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Dated

G. J. Sharpe
27 JUL 2000

1/77

19 JUL 99 E462853-2 C46110

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The Patent Office

Cardiff Road
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1. Your reference

HPK / SWEECPI 7 / 99

2. Patent application number

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9916779.3

3. Full name, address and postcode of the or of each applicant (underline all surnames)

H-P G KELLY47 CROWSTONE ROADWESTCLIFF ON SEAESSEX SS0 8BG1702665001

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

4. Title of the invention

SEA WAVE TO ELECTRICAL ENERGY CONVERSION PLANT

5. Name of your agent (if you have one)

Address for service in the United Kingdom
to which all correspondence should be sent
(including the postcode)

47 CROWSTONE ROAD

WESTCLIFF ON SEA

FLOODES ESSEX SS0 8BG

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Country Priority application number Date of filing

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- any applicant named in part 3 is not an inventor, or
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PATENTS ACT 1977

SPECIFICATION

for

PATENT APPLICATION IN UNITED KINGDOM

ENTITLED

Sea Wave to Electrical Energy Conversion Plant

in the name of: Hugh-Peter Granville Kelly,
of 47 Crowstone Road, Westcliff on Sea, Essex

Sea Wave to Electrical Energy Conversion Plant

The present invention relates to the production of electrical energy from natural renewable sources, specifically wave power.

Numerous devices have been devised to capture and convert to electricity the vast amounts of energy available from sea waves. In each case however, the practicality of use of these devices, along with their associated relatively high capital cost, has hindered their commercial success, as compared to the use of wind power generators, which are well established. At the root of this lack of success is the inherent complexity, and relative inefficiency of the design of existing wave energy capturing devices. In the case of one existing family of such means, the essentially reciprocating vertical action produced by waves as they undulate must first be converted to a rotary motion to drive a conventional rotary electrical generator. An example of such a mechanism is the oscillating water column device, in which a tube, open to the atmosphere, is immersed in the sea. Mounted within the open end of the tube is a fan, which is used to turn a rotary generator. As the waves ascend and descend, air is pushed out and sucked through the open end, turning the fan and so generating power. This, and many other devices, all rely upon various forms of mechanical conversion mechanism to convert the oscillatory motion of waves into rotary motion, in each case in order to rotate a conventional generator.

This invention is concerned with an alternative and preferred family of means for obtaining electrical energy from the motion of waves, namely the direct conversion of wave movement to electrical power using electrical linear generators. In this arrangement, the motion of floats is used to cause relative movement between the stator and armature of such a generator, and thus the direct generation of power without the need for any form of intermediary mechanism.

An important factor affecting the generation of electricity from any source, is the efficiency of energy conversion. This is particularly important in the case of capturing renewable energy from sea waves. Because of the cost of installing the power conversion plant, the operator must be absolutely certain that the commercial returns will be adequate. It is not possible simply to step up output by burning more fuel, as, obviously, the behaviour of the fuel source (the sea) is outside the operator's control. Thus, in the case of wave power generators using linear generators as the energy conversion means, every possible watt of energy must be extracted to ensure an adequate return. For this purpose, it is essential both to ensure that the apparatus is arranged to generate power as consistently as possible, and also not to waste the potential energy available from the sea waves on any function subsidiary to the generation of power.

An example of such a subsidiary function affecting the performance of many designs of wave conversion plant using buoyancy chambers, is the expenditure of wave energy necessary to accelerate the mass itself of the buoyancy chamber and any associated apparatus not directly concerned with the conversion of power. For example, in the case of buoyant hinged raft type constructions, which are used to

According to the invention, wave energy to electrical energy power conversion plant comprises one or more floats, immersed in waves, for causing relative movement between the stator(s) and armature(s) of one or more linear generators, and thus the generation of electricity, the construction of the float(s) being such that they are made as buoyant as possible commensurate with adequate structural strength for their function, and the orientation, number and / or size of the linear generators being acted upon by the float(s), being so arranged and chosen that their gravitational weight, together with the gravitational weight of the float and any intermediate means necessary to link the float to the aforesaid generators, is such that the upthrust provided by the water displaced by the full volume of the float(s) is substantially half counteracted by the combined weight of the aforesaid weights.

Thus, in this arrangement, were there to be no waves, ie calm conditions were prevailing, because of the effect of the combined weights, the float would float half in / half out of the water. Thus, in the presence of waves, during the rise of a wave, (and assuming the mmf resistance afforded by the generators to the motion of the float is such that it is completely submerged during this rising phase), an upwards thrust is imparted to the generator equal to substantially half the weight of the water displaced by the float, and on the downstroke, assuming the float is hardly in contact with the water, a downwards thrust is imparted to the generator equal to the combined weights of the assembly, again equal to substantially the same value as was experienced on the upstroke. No energy is therefore lost in accelerating any parasitic weight other than the right number of moving component(s) of the linear generators to provide consistent upwards and downwards thrust, and thus consistent generation of power during both these phases. All of the available force

arising from the motion of the float upon the waves, and thus the captured energy, is expended in the movement alone of the generators for doing useful work (setting aside the comparatively small amount of energy necessary to accelerate any intermediate linking means, and the lightweight float itself). By this means, it will be appreciated that it is singularly the very weight of the linear generator moving component part (s), (and to a much lesser extent, the weight of any intermediate linking means and the weight of the float itself) which is used to optimise the motion of the float for the consistent and optimum generation of power.

By way of introduction to an embodiment of the invention described below, many other forms of wave energy devices cannot, by their very construction, make optimum use of the sea area available in which they operate. For example, in the case of the type of device in which buoyancy chambers are affixed to the far ends of swivelling arms for operating hydraulic pistons, with the opposite ends of the arms being pivoted within a tower mounted on the sea bed containing the hydraulic piston and other components, a considerable sea area is monopolised by the arms and the tower itself. This sea area cannot therefore be used to do useful work. In an ideal world, and to obtain the maximum energy from a given area of the sea, as many floats as is possible should be operative within the waves, without of course disrupting their natural flow and thus effectiveness. It can be envisaged that a honeycomb arrangement of floats would provide an idealised solution.

Therefore, in an embodiment of the invention, the disposition, size and number of linear generators operated by the float / floats is so arranged and chosen that the average horizontal area occupied by them does not exceed to any material extent

the horizontal area occupied by the float(s) used to operate them (and any perimeter space surrounding the float for the effective operation and motion thereof). In this arrangement, the generators do not therefore occupy any space greater than that of their associated floats, and thus as many floats can be juxtaposed side by side, or in any other favourable arrangement, as is possible. Thus, for any given sized sea area, and thus size and cost of associated support structure for housing the linear generators, the maximum power may be generated and therefore the greatest financial return obtained for initial capital outlay.

In a feature of the invention, in order to enhance the captivation of wave energy, the flotation chambers are equipped with one or more paddles immersed in the sea, the planar axes of the paddles being arranged to be substantially parallel to the sea surface, the arrangement being such that the float and paddles act -in combination- to force movement of the armature of the generator(s) relative to its stator, the float by means of its buoyancy, and the paddle, or paddles, by means of their resistance to the motion of the seawater. Furthermore, the planar surfaces of the paddle against which the rising and falling water presses, may be so contoured as to provide as much resistance as possible to the motion of the water, and therefore to receive the greatest counter thrust.

In a further feature of the invention, relating to the shape of the floats, their profile is optimised such as to provide the maximum possible buoyancy while offering minimal resistance to the slight elliptical horizontal movement experienced by waves as they rise and fall. Thus minimal sideways forces are communicated to any support structure supporting the linear generators. This profile may be, for example, in the

shape of a 'flying saucer'.

Numerous forms of linear motor exist which can act as linear generators, but one particularly favoured for this application on account of its symmetrical tubular construction, relatively low cost, and inherent suitability for this application, is as described in my UK granted patent no. UK 2079068. Many thousands of these motors are now in use in applications world wide. The construction of this motor comprises a stator in the form of a rod, (known as the 'thrust rod'), and a cylindrical armature, (known as the 'thrust block'), for coaxial travel along the stator. The rod comprises of a series of permanent magnets held within a protective tube, and which are interspaced and in a particular NS...SN...NS sequence, and the armature comprises a series of contiguous annular coils, sealed within a tubular housing. In use as a linear motor, energisation of the coils in the correct sequence results in electromotive force in a desired direction, and so movement of the armature relative to the stator. Conversely, as a generator, forced movement of the armature relative to the stator causes AC electrical currents to be generated.

In a further embodiment of this invention, a linear motor of this type is used as the generator. In a first arrangement, the stator thereof is partially immersed in the sea, and is held perpendicular to the sea bed by a weight resting on the sea floor, or by other permanent means. The coaxial armature for traversing up and down the rod, and the generation of electricity, is directly fixed to, or is integral to, the flotation chamber -and paddles- which are also coaxial with the rod and free to travel therealong. In use, and in accordance with the invention, the gravitational weight of the armature, along with that of the flotation chamber is so predetermined that

substantially half of the flotation chamber would protrude above water during calm conditions. Thus, in wave conditions, as waves ascend, its natural buoyancy raises the assembly to generate electricity, and as the waves fall, the weight of the assembly causes it likewise to fall, again generating electricity. To suit local conditions, in a feature of this embodiment of the invention, rather than using one coaxial flotation chamber per motor, one large flotation chamber may be linked by articulated joints to several generators.

In an alternative arrangement relating to this embodiment of the invention, the linear generator, or generators, rather than being immersed in the sea, is / are instead mounted within a supporting cage above sea level. The generator may be protected from sea spray and the wind by suitable cowlings. In this arrangement, the flotation chamber and paddles -moving in response to the undulation of the sea waves- are connected by push rods, or other mechanical means, to the moving part of the housed generator (s). Thus, the aggressive and inhospitable aspect of generating power from waves is confined solely to the field (ocean) replaceable flotation and paddle components. In an aspect of this form of arrangement, in order to cope with the very considerable variations in wave height arising from tidal movement affecting power plants located near the sea shore, means are provided within the cage to vary the height, relative to the sea bed, of the fixed part of the generator, in accordance with the mean height of the waves. In yet a further aspect, the cage is itself mounted on a trolley, free to run on rails following the direction of the tide, for example down a beach, so also maintaining the flotation chamber at the correct height relative to the waves.

In yet a further embodiment of the invention, where it is desired to generate greater

power per unit length of linear generator than would be possible with the above described type of linear generator, an alternative form may be employed in which the form of armature is the same as that already described, but where the stator magnets, rather than being spaced apart in a NS...SN....NS... sequence, instead abut one another, so that the faces of like poles are physically touching, ie in a NSSNNS sequence. In this case, the flux density experienced by the armature coils is increased somewhat, and therefore similarly the power generated, albeit at a greater cost of construction because magnets are disposed in a solid pile along the length of the stator, rather than being spaced one from another.

Referring now to an aspect of the invention concerned with how generation of electrical power is optimised for any given prevailing wave condition, control means are used to regulate the effective load impedance presented to the generators in accordance with the strength of the prevailing wave motion, the regulation being such as to ensure that the electromagnetic damping of the motion of the generators, as they generate electricity, is always such as to optimise the generation of power. By way of explanation, if the generator is either over or under damped, it will fail to respond in the optimal manner to movement of the waves, inasmuch that its response frequency will not enable sympathetic motion corresponding to that of the waves.

According to an aspect of the invention, a method for converting wave energy to electrical energy comprises the use of one or more floats, immersed in waves, for causing relative movement between the stator(s) and armature(s) of one or more linear generators, and thus the generation of electricity, the construction of the

float(s) being such that they are made as buoyant as possible commensurate with adequate structural strength for their function, and the orientation, number and / or size of the linear generators being acted upon by the float(s), being so arranged and chosen that their gravitational weight, together with the gravitational weight of the float and any intermediate means necessary to link the float to the aforesaid generators, is such that the upthrust provided by the water displaced by the full volume of the float(s) is substantially half counteracted by the combined weight of the aforesaid weights.

The invention will now be described with reference to the accompanying drawings in which:-

Fig 1 is a schematic representation of a wave generator of the invention,

Figs 2a b & c show alternative arrangements to those of Fig 1

Fig 3 shows yet a further alternative arrangement to that of Fig 1,

Fig 4 shows details of bearing arrangements for guiding the armature of the generator relative to its stator, as well as barnacle cleaning means,

Fig 5 shows an arrangement in which the generators are mounted above sea level in a cage.

Fig 6 shows a multiplicity of generators mounted above and within the confines of the horizontal surface area of a float

Fig 7 shows typical electrical current waveforms generated by the wave movement, and control circuitry for optimising the use of the available wave power in any set of prevailing conditions,

Referring to Fig 1, wave energy to electrical energy conversion apparatus is depicted immersed in the sea. The apparatus comprises a float driven linear generator, the stator of which comprises a fixed rod 10, which houses a sequence of permanent magnets. The rod is embedded, at its lowest extremity, in a concrete block, 11. The block itself is anchored to the sea bed -shown generally at 12- to avoid drifting.

The armature of the generator 13 comprises a cylindrical housing in which is embedded a series of contiguous coils. (The generator can be, in one embodiment of the invention, a linear motor as described in my granted patent number UK2079068, but used in reverse as a generator.) Coaxially surrounding the armature, and affixed thereto, is an annular flotation chamber 14. Located at the upper and lower surfaces of the armature are bearing blocks 15 and 16, for guiding the armature coaxially up and down the stator. Annular paddles 17, are also affixed to the flotation chamber. The paddles are contoured in order to offer as much resistance as possible to vertical movements of the sea water, see inset diagram at 17a. In accordance with the invention, the size and/or length of the armature of the linear generator, and thus its weight, is so selected that its weight, combined with that of the float, is such as to counteract by half the total upthrust afforded by the volume of water that would be displaced by the float were the float to be submerged.

The action of the apparatus is as follows. As a wave arrives, the natural buoyancy of the flotation chamber causes the whole assembly to rise. This is assisted in significant measure by the pressure of the rising water acting against the paddles 17. Thus relative motion arises between the armature and stator of the linear generator and alternating current is generated within the coils of the generator, the amplitude and frequency of which depend upon the vigour of the wave motion. The current is conducted to a shore station by a suitably armoured and flexible cable, 18. (Note, means, not shown, are present to prevent rotation of the assembly and therefore unwanted tensioning of the cable.)

Once the wave has reached its zenith, and begins to fall, the weight of the assembly causes the same also to fall. Power again is generated as the armature traverses the stator. Because the upthrust experienced by the generator is substantially the same as the weight of the assembly, electricity is generated reasonably consistently both upon the rise and fall phases of the wave. There is some natural phase lag between the ascending of the assembly relative to the waves, and its fall, due to the natural damping effect of the electromotive force generated. As will be hereinafter described in more detail, the load impedance presented to the generator, and the overall weight of the moving assembly, is so selected as to optimise generation for any particular wave condition.

The apparatus of the invention thereby generates electrical energy consistently by the simple expedient of using an elongate linear motor of appropriate weight acting in reverse as a wave powered linear generator. It will be appreciated that in this sea immersed embodiment of the invention, most of the apparatus is submerged. Unsightliness is therefore avoided, providing 'an environmentally friendly' generating means.

Referring now to Figs 2a and 2b, two variations to the arrangement of Fig 1 are shown. In order to minimise capital cost, rather than employ several generators, each equipped with their own individual flotation chamber, an alternative arrangement is to utilise one larger flotation chamber 19, with paddles 20, affixed to several generators, 21. In the case of particularly large arrangements, the flotation chamber, rather than being rigidly affixed to each generator, may instead be connected to each by means of swivel joints, (see details in Fig 2c), so permitting

the chamber to respond more naturally to the undulation of the waves, while still effecting relative movement of each armature relative to its corresponding stator. Again, and in accordance with the invention, the combined weight of the float and the generators is such as to exert a substantially equal upthrust as downthrust.

Figure 3 shows yet a further arrangement of the apparatus of the invention, in which the linear generator 22 is protected from the sea by an annular protective coaxially mounted cylinder 23, also embedded in the concrete block, 24. In this case, thrust from the float and paddle arrangement 25, is communicated to the armature of the generator by a double cylinder arrangement, 26. Slidable seals, 27, ensure that the generator is protected from the ingress of sea water.

Referring now to Fig 4, means for guiding the armature of the linear generator along its stator, is depicted generally at 28. A substantial and field replaceable plastics bush 29, is mounted at each end of the armature coil housing, 30. The bush acts as the sliding means for guiding the armature. Affixed to the bush is an elasticated conical shroud, 31, permanently slidably pressing against the stator. The purpose of this shroud is to scrape off barnacles, (not shown), and other sea debris which may attach to the rod in protractedly long calm conditions. As an alternative to the bush, roller bearings supported by a spider may be employed. Note, because the linear generator can also be driven as a linear motor, it can occasionally be driven from eg the shore station, in open loop mode, to forceably undergo a periodic cleaning routine.

Where visual environmental considerations are not of importance, as an alternative

to the immersing of the generator in the sea, and/or when generation is to be effected at a sea depth when it is impractical to use the arrangements of Figs 1-3, an alternative method of mounting the generator may be employed with many practical advantages. Referring to Fig 5, rather than the generator being immersed in the sea, it is instead mounted within a cage 32, which in this illustration, itself rests on and is anchored to the sea bed. (Alternatively, in the case of operation in deep waters, the cage could be supported on the sea surface by separate buoyancy chambers, and moored by anchor to the sea bed.) In this arrangement, the moving part of the generator is the stator 33. For the purpose of economy of construction, not all of the stator contains permanent magnets. On the contrary, the stator tube is only filled with magnets in its active central portion. The portions 33a and 33b which extend respectively downwards to the float 34, and upwards through the guide rollers 35, are instead filled with a material of appropriate durability and structural strength. As can be seen from the figure, the armature 36, is mounted on a platform 37, within the cage. As the float and paddle combination 34 is caused to ascend/descend by the undulation of the waves, so the stator is moved through the fixed armature to generate power. The stator is guided by the rollers, 35 and 36.

As is well known, there can be significant variations of the height of the sea close by the sea shore due to tidal motion. Thus, according to the time of day, the height of the peaks and troughs of any 'given size' may vary substantially relative to the sea bed. This must be accommodated in the case of near shore location of any of the arrangements herein disclosed, by means of having a sufficiently long stator rod. However, filling such a rod along its whole length with magnetic material, so that an 'active portion' is always presented to the armature, entails undue expense. As

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mentioned above, not all of the tube is so filled. Instead, and in accordance with a feature of the invention, the armature may be situated on a vertical movable platform, 37. The height of the platform may be adjusted by detection means, (not shown), to vary with the mean height of the waves, ie the average tidal level, by lead screw actuators, 38. The armature may be cooled in use by sea water pumped around a cooling jacket surrounding the same.

To achieve the same economies, but by different means, rather than by utilising a movable platform 37, the entire cage may be mounted on rails, not shown, for travel in the direction of the tide, to maintain the action of the float, and therefore movement of the generator equidistant around its central point.

To achieve the optimum performance of energy conversion apparatus using floats and linear generators, it can be advantageous in certain oceanic locations where large waves are present to use a large float. An example might be a float having a displacement of ten to twenty tons. In this case, because the force communicated to the generator is very considerable, it is mechanically impractical to use a single elongate linear generator. The reason for this is that in order to properly exploit the thrust available from the motion of the float, in other words to generate an mmf capable of providing a mechanical force opposite and nearly equal to the thrust, both the stator and armature would have to be disproportionately long. In this case it is preferential to use a multiplicity of generators, all acted upon simultaneously and - for the sake of symmetry- to the same degree by the one single float. Such an arrangement is shown in Fig 6. A single shaft shown at 40, used to transmit the force exerted by the float, drives the stators 41 of several parallel generators 42 to

and from through their linked armatures 43. By this means, sufficient mmf is generated to 'use up' the thrust provided by the float, but without having to use generators of undue length. Furthermore, the combined weight of all of the stators 41, in addition to the shaft 40, is used -in accordance with the invention- to half counteract the full displacement of the float.

It will be appreciated that in practice the multiplicity of generators could be arbitrarily positioned relative to the float, provided that the upthrust is mechanically communicated satisfactorily to them.

However, in accordance with a feature of the invention, a balance is achieved between the length of the linear generators and the total number used for any given float, such that -while achieving the necessary mmf resistive force, the total horizontal area occupied by them falls within the equivalent horizontal area occupied by the float (as is shown in Fig 6). By this means, floats can be closely juxtaposed in order to make optimum use of the sea area in which they are immersed, and thus achieve the largest possible conversion of sea wave energy to electrical energy for a given area. This additionally provides the maximum return in terms of revenue for each kilowatt hour generated, for a given capital outlay on support structures.

For any given sea condition, which may vary from a light swell to a raging storm, it is important to ensure that the moving part of the generator faithfully follows the movement of the waves. For example, should the armature be feeding a short circuit, its motion would be excessively damped, and the float / paddle combination would be unable to follow the waves in an optimal fashion. Similarly, in a storm,

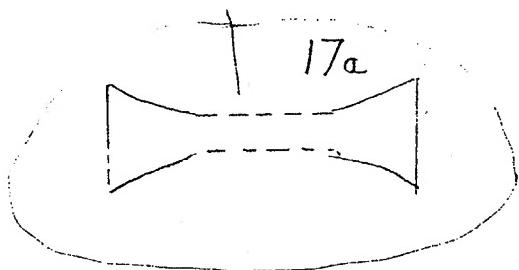
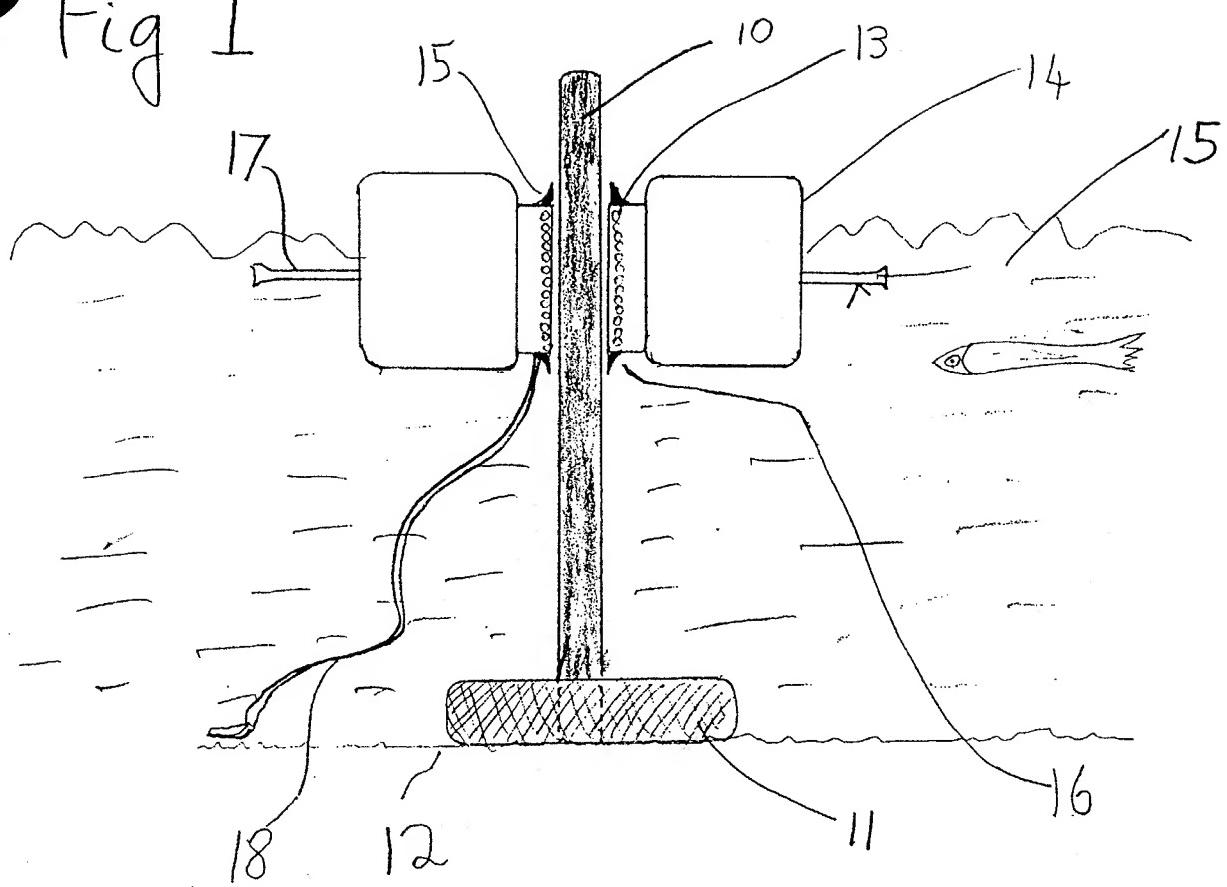
were the generator to be feeding effectively an open circuit, the assembly may rise too easily in response to an approaching wave, and overshoot the crest thereof. Therefore means are necessary to ensure the load impedance is suitably adjusted for any given wave pattern. Referring to Figure 7, AC currents generated within the armature coils of the generator, shown symbolically by way of example at 44 and 45, are first rectified by bridge rectifiers 46 and 47. The resulting DC currents are then fed into storage means 48. The storage means assists both in producing a steady DC level, and for ensuring a constant supply of energy whether a storm is present, or an intervening calm. An inverter 49, is used, via a transformer 51, to supply alternating current to the electricity distribution system.. The effective impedance of the inverter is dynamically adjusted by detection means 50 which itself is responsive to the form of current the generators are attempting to generate,in order to optimise generation of power for any given wave condition. Thus the criteria outlined above for ensuring optimal matching of the generating capacity of the generator, with that of the motion of the waves, is permanently self optimised. Other control circuitry means, (not shown), are used -as is customary in generating stations- to ensure the phase angle of the generated currents is correct for the addition of power to the distribution system.

An additional feature of the invention, which indeed can be applied to all the arrangements described herein, is that the permanent magnets within the stator rod may, according to their position along the rod, be made of permanent magnetic materials of varying field strengths and therefore cost, such that at the middle of the stator, where motion of the armature will be at its greatest, are located the strongest magnets, and at the extremities of the rod, weaker magnets. This arrangement can

thereby also be used to match the predominant wave conditions, as well as economising in the cost of magnets used.

Numerous variations of the above will be apparent to those skilled in the art.

Fig 1



A sketch in the name of

Fig 2a

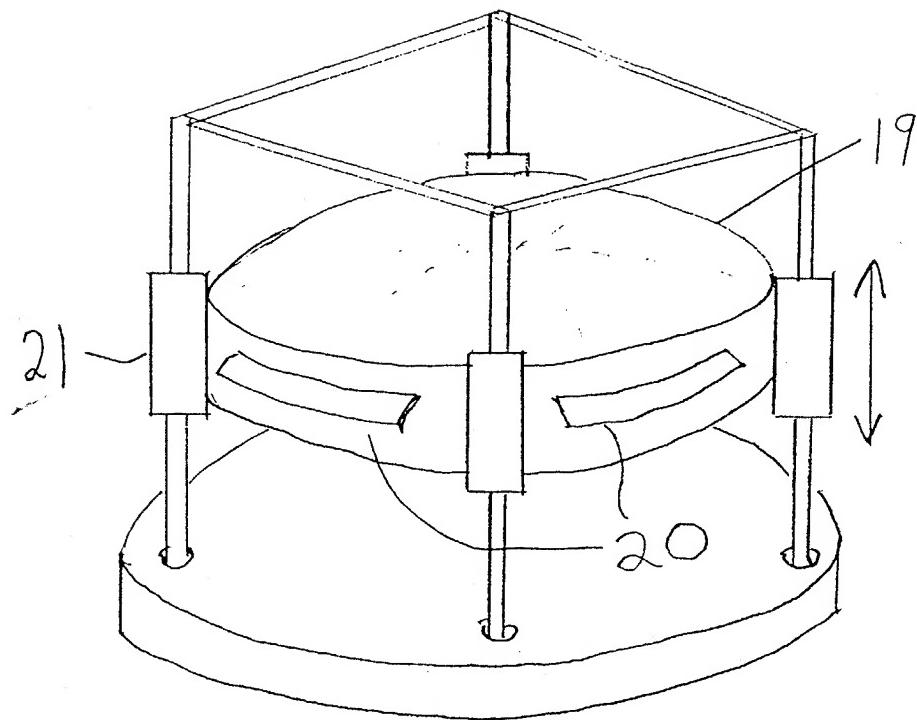


Fig 2c

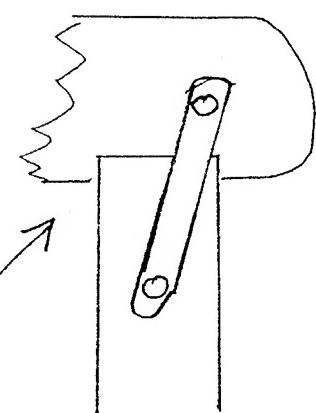


Fig 2b

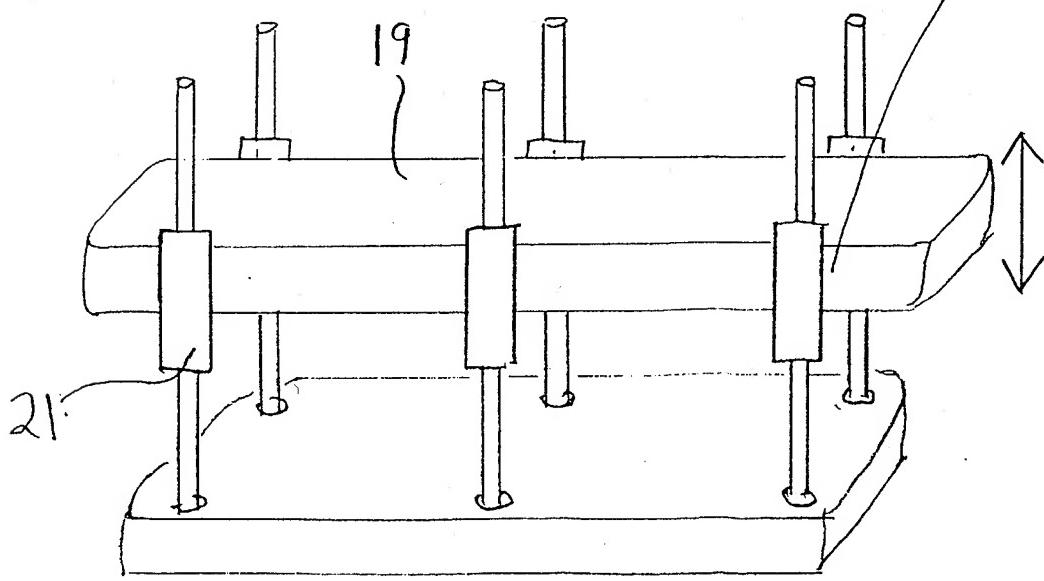


Fig 3

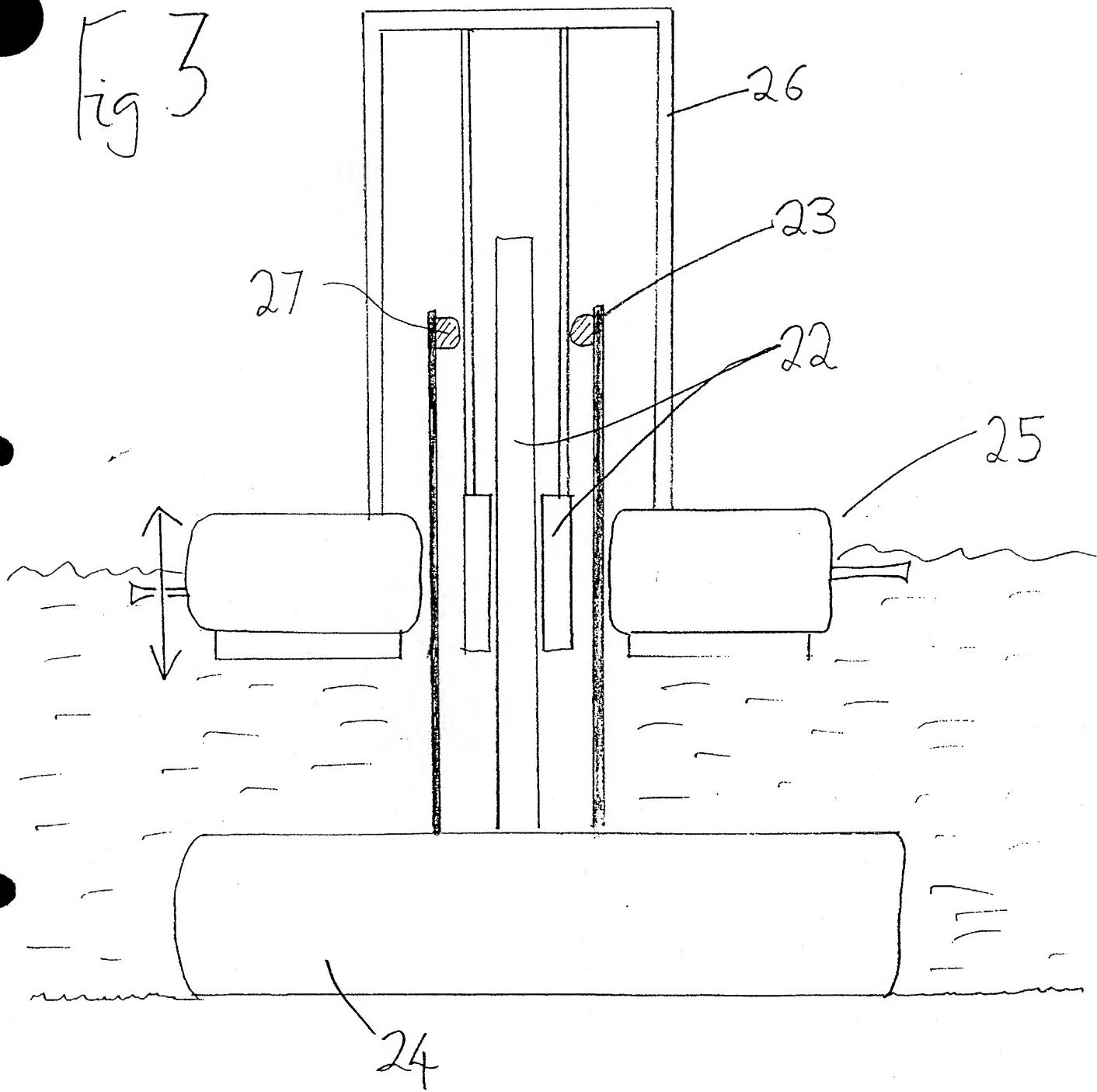
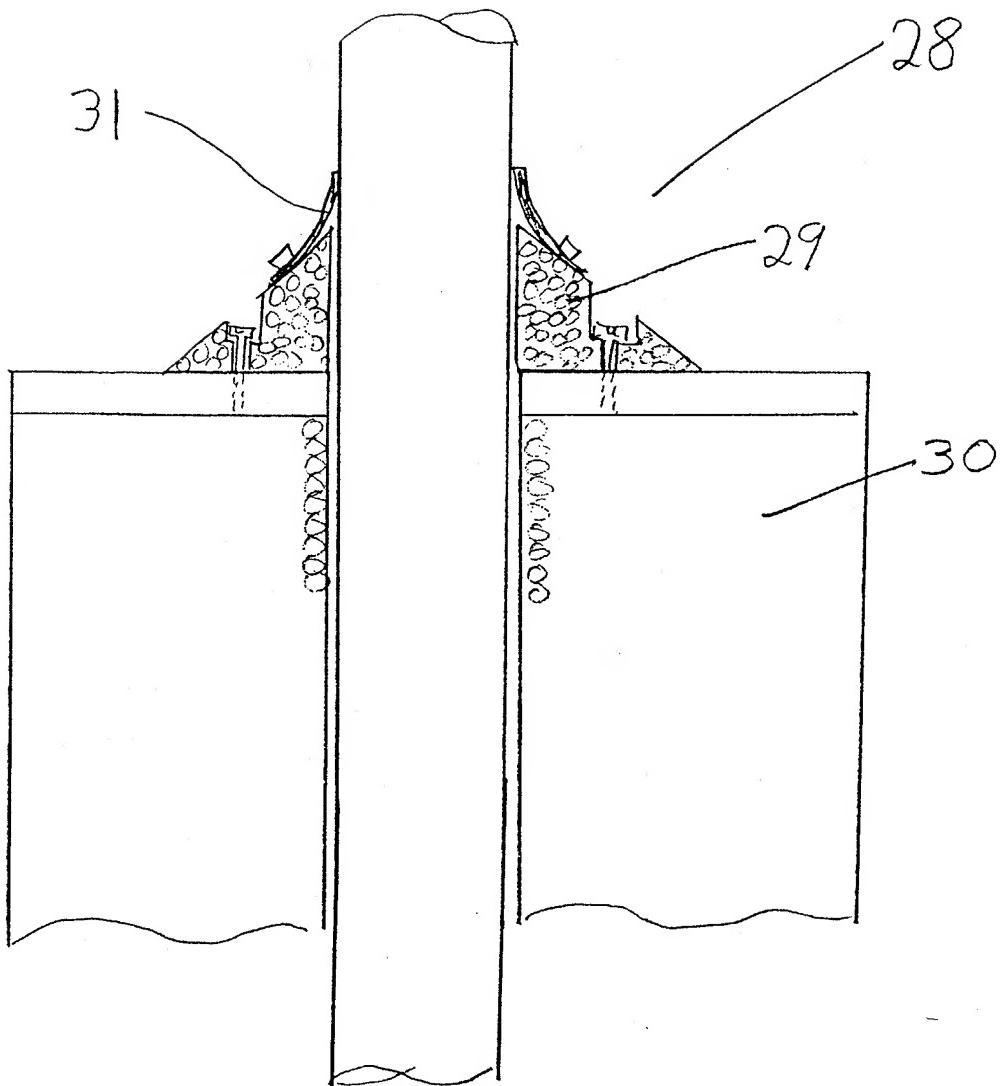
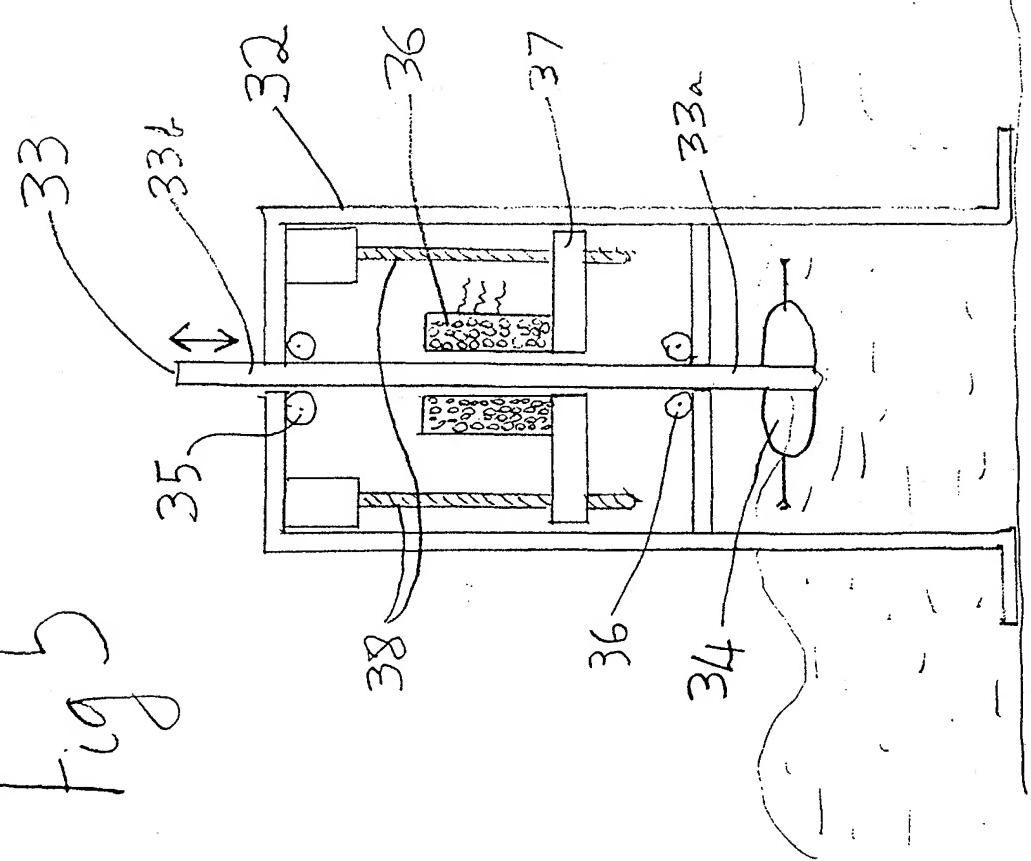


Fig 4



Anastomosis in the nose?

Fig 5



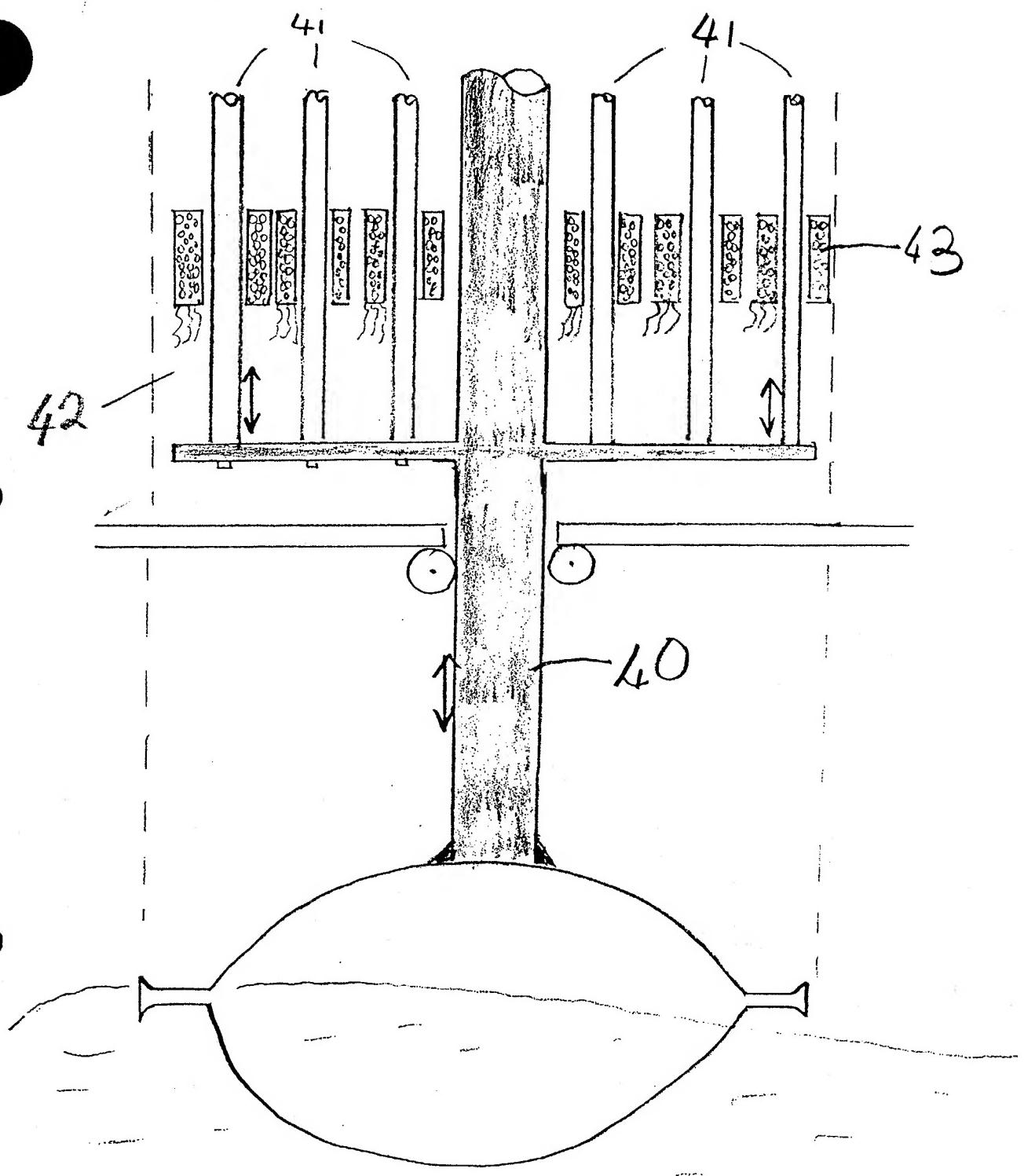
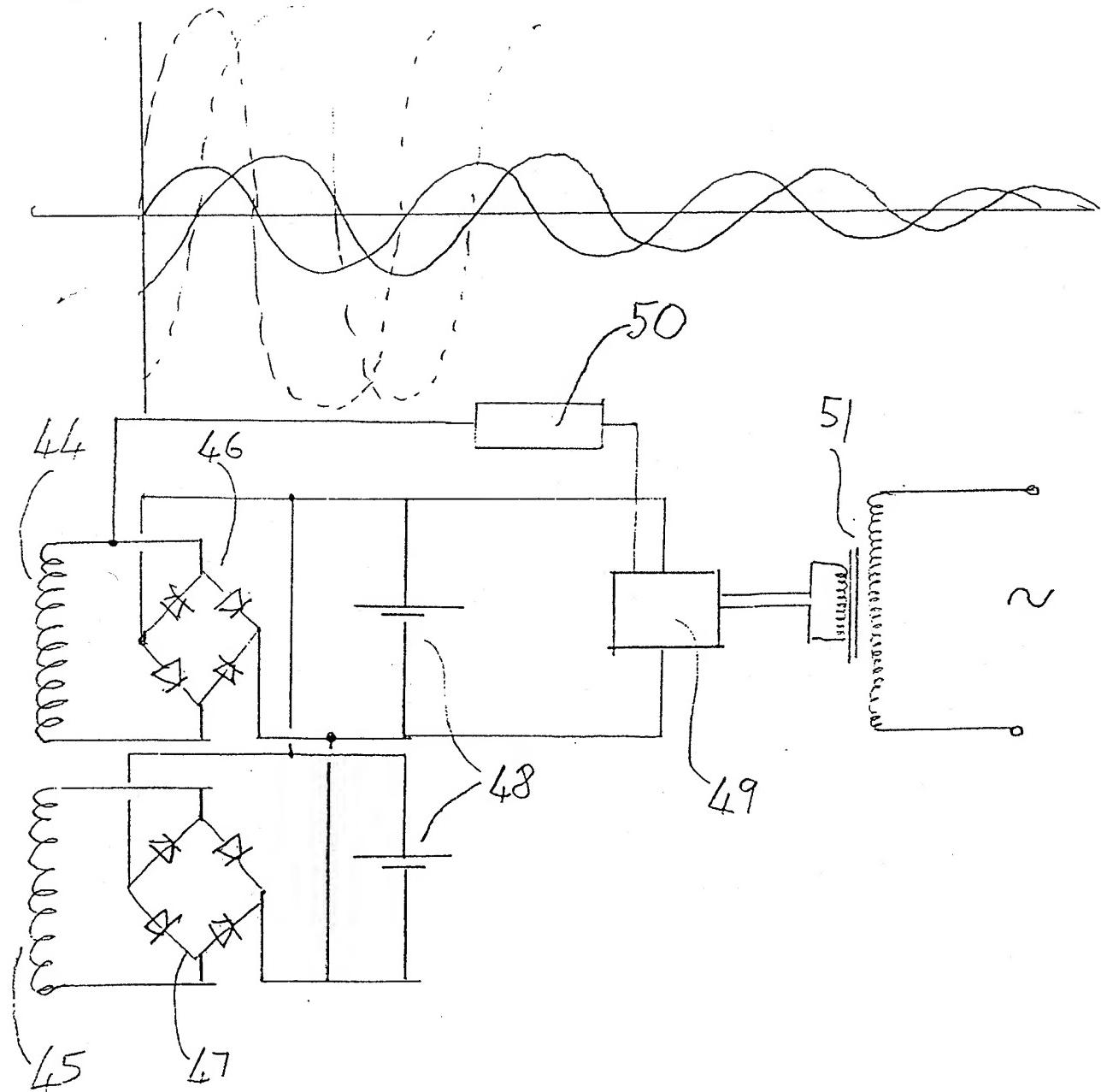


Fig 6

Application in the name of

Fig 7



Application in the name of